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Does a learning curve exist for accuracy in three-dimensional planning for maxillary positioning in bimaxillary orthognathic surgery?

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Abstract. The purpose of this study was to investigate the influence of time, and experience, on the accuracy of maxillary repositioning in bimaxillary orthognathic surgery performed using virtual surgical planning (VSP). Patients who had undergone bimaxillary orthognathic surgery were reviewed. Maxillary position on pre- and postoperative computed tomography scans was compared. The patients were divided into groups according to the year in which VSP was performed and surgery completed. Linear distances between upper jaw reference landmarks were measured in all three planes of space to determine accuracy between the preoperative VSP and the surgical outcome at various time points. One hundred subjects met the eligibility criteria for assessment and were allocated to groups: 2013 ($n = 10$), 2014 ($n = 17$), 2015 ($n = 39$), 2016 ($n = 20$), and 2017 ($n = 14$). Overall, the results demonstrated improved precision in maxillary position over the years, with more accurate results in patients who underwent surgery in 2015, 2016, and 2017. Mean linear differences between planned and obtained results demonstrated more accurate results in the horizontal direction, followed by transverse and vertical directions. An overall average difference within 1 mm was observed for 51.3% of the measurements included in the sample group. Time, and surgeon experience, can influence the accuracy of maxillary positioning in bimaxillary orthognathic surgery.

Key words: orthognathic surgery; virtual surgical planning; VSP; osteotomy.

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Patients with dentofacial deformities often require surgical correction of their skeletal abnormalities to improve functional limitations, mainly mastication and speech, as well as to achieve facial esthetic harmony. Orthognathic surgery is the most common surgical intervention for such cases, and establishing the correct position of the maxilla is a key element in achieving successful results[1,2]. Failure to position the maxilla correctly in three planes of space may lead to poor esthetic and functional results.

With the development of computerized technology, orthognathic surgical planning in many centers has shifted from conventional clinical evaluation with cephalometric planning and model surgery, to the use of computer-aided design/computer-aided manufacturing (CAD/CAM) principles and virtual surgical planning (VSP). The proposed advantages of the VSP database include the creation of more precise surgical treatment plans and multiple plans with ease, decreased surgical planning time, and improved surgical outcomes.

In 2007, Xia et al. published a pilot study assessing the accuracy of a computer-aided surgical simulation (CASS) system in the treatment of patients with complex craniomaxillofacial deformities[3]. By superimposing initial and postoperative computed tomography (CT) scans to evaluate outcome accuracy, the authors found promising results. A prospective multicenter study performed years later confirmed accurate results as well. Hsu et al.[4] assessed the accuracy of a CASS protocol for orthognathic surgery and reported excellent accuracy for the maxillary dental midline position. The differences between the planned and postoperative outcomes in the maxilla were 0.8 mm for mediolateral, 1.0 mm for anteroposterior, and 0.6 mm for superoinferior measurements[4].

Zhang et al.[5] also evaluated the accuracy of VSP in 30 consecutive patients who underwent two-jaw orthognathic surgery, by measuring mean differences in maxillary landmarks between virtually simulated and postoperative CT scans. The results showed that the VSP was successfully transferred to the operating room, leading to a mean difference between planned and postoperative measurements of 0.81 mm (0.79 mm for maxilla and 0.91 mm for mandible)[5]. Similar results were also obtained by Kwon et al.[6], who reported a mean discrepancy between planned and obtained results of 0.95 mm for VSP, showing satisfactory accuracy in maxillary repositioning when using VSP[6]. Furthermore, a recent study demonstrated maxillary accuracy when orthognathic surgery was planned virtually, with a mean difference between the virtual plan and postoperative result of 0.79 mm for maxillary position[7]. After 7 years of experience using VSP for craniomaxillofacial surgery, Adolphs et al. reported many advantages of this technology and emphasized that further improvement of the preoperative workflow could be expected over the years[8].

Previous investigators have demonstrated accurate results when using VSP in orthognathic surgery[3,9], although there is a lack of information regarding whether outcomes have differed based upon software updates, as well as VSP learning experience and comprehensive training of the surgeon. To address this gap in knowledge, the goal of this study was to assess how technological advances and surgeon experience impact upon planning accuracy and surgical outcomes. The hypotheses of the study were (1) there are no significant differences between the planned and actual maxillary position, and (2) there is no difference in the accuracy of virtual orthognathic surgical planning with time and experience.

Materials and methods

This retrospective case–control study, in which the control was determined by the surgical planning of each respective individual, investigated consecutive adult patients who underwent two-jaw, maxilla-first orthognathic surgery between March 2013 and September 2017. All cases were planned and performed by a single surgeon (MM) using VSP, with a single third-party biomedical engineering group (3D Systems, Rock Hill, SC, USA). The study was previously approved by the University of Illinois at Chicago Institutional Review Board (IRB protocol number 2108-0276) and was performed following the Declaration of Helsinki protocol.

Inclusion criteria were adult subjects with a history of bimaxillary orthognathic surgery, and the availability of surgical planning records. Patients were excluded as subjects if there were missing or deficient records, they had undergone concomitant temporomandibular joint surgery, or if the orthognathic surgical sequencing had been mandible-first.

The surgical procedures included a Le Fort I osteotomy according to the conventional method described by Bell[10]. A Kirschner wire inserted at nasion and an intermediate surgical splint were used to determine the vertical, anteroposterior, and transverse maxillary position. After the elimination of bony interferences, the maxilla was fixated with four L-shaped titanium miniplates and 16 self-drilling screws (KLS Martin, Jacksonville, FL, USA). The mandible was then osteotomized using a bilateral sagittal split osteotomy (BSSO) as proposed by Hunsuck[11]. The distal segment was positioned into the final occlusion using the final surgical splint and fixated with one miniplate and four monocortical screws on each side. An adjunctive genioplasty procedure was performed (with or without VSP planning and surgical guides) via an inferior border horizontal osteotomy, with chin advancement or setback when necessary, and a preformed chin plate and monocortical screws were used for fixation.

Pre- and postoperative cone beam computed tomography (CBCT) scans of all selected cases were imported into Dolphin Imaging Software, version 11.9 (Dolphin Imaging and Management, Chatsworth, CA, USA). Preoperative CBCT scans had yaw orientation with nasion and basion aligned as the sagittal midline, roll orientation with the orbital floors at the level of infraorbital canals aligned, and pitch adjusted with right porion and right orbitale at the same level forming the Frankfort horizontal plane. Next, postoperative CT scans, acquired up to 45 days after orthognathic surgery, were registered onto the previously aligned preoperative anterior cranial base using the voxel-based matching superimposition feature present in Dolphin software[9].

To evaluate the accuracy of maxillary repositioning, three landmarks were used as references and marked on both the pre- and postoperative CBCT scans using sagittal, axial, and coronal images. These were (1) the midline between the upper central incisors (U1 midline), (2) the upper right first molar mesiobuccal cusp (RU6), and (3) the upper left first molar mesiobuccal cusp (LU6). Two cranial base landmarks (basion and nasion) were also positioned; these were used for operator calibration only. The spatial positions of all landmarks in all three axes (x, y, and z) were then transferred to a Microsoft Excel spreadsheet (Microsoft, Redmond, WA, USA) using a software tool called 'copy landmarks coordinates'. The numerical values for the preoperative coordinates were added/subtracted to/from the VSP report transverse, vertical, and horizontal measurements for maxillary position, according to the planned movement for each case. A new value (preoperative coordinates + VSP measurements) was obtained and comprised the planned coordinate for each landmark. The numerical differences between the postoperative coordinates and the planned coordinates of all three maxillary landmarks were used to define the accuracy of maxillary positioning. A single operator identified all landmarks and coordinates on two separate occasions, in a blinded manner; the mean of the two values was used as the final measurement for pre- and postoperative coordinates.

Table 1. Differences between pre- and postoperative measurements for the nasion and basion landmarks; values are the mean difference and standard deviation.

Landmark – axis	Year					*P*-value*
	2013 $n = 10$	2014 $n = 17$	2015 $n = 39$	2016 $n = 20$	2017 $n = 14$	
Basion – x axis	0.41 ± 0.27	0.58 ± 0.28	0.52 ± 0.34	0.44 ± 0.20	0.49 ± 0.30	0.564
Nasion – x axis	0.59 ± 0.20	0.52 ± 0.30	0.48 ± 0.30	0.46 ± 0.42	0.41 ± 0.29	0.719
Basion – y axis	0.17 ± 0.21	0.61 ± 0.36	0.61 ± 0.40	0.70 ± 0.45	0.24 ± 0.48	0.468
Nasion – y axis	0.59 ± 0.26	0.52 ± 0.29	0.43 ± 4.70	0.71 ± 0.39	0.38 ± 0.35	0.864
Basion – z axis	$0.37 \pm 0.18^{a,b}$	0.24 ± 0.15^{a}	0.51 ± 0.36^{b}	$0.42 \pm 0.33^{a,b}$	$0.45 \pm 0.34^{a,b}$	0.003
Nasion – z axis	0.63 ± 0.28	0.26 ± 0.19	0.69 ± 2.53	0.45 ± 0.23	0.47 ± 0.35	0.508

* *P*-value: different letters represent statistically significant differences between values.

Table 2. Differences between planned and postoperative results for all landmarks in all axes; values are the mean difference and standard deviation.

Landmark – axis	Year					*P*-value*
	2013 $n = 10$	2014 $n = 17$	2015 $n = 39$	2016 $n = 20$	2017 $n = 14$	
U1 midline – x axis	1.79 ± 0.60^{a}	1.27 ± 0.83^{b}	$0.87 \pm 0.69^{b,c}$	0.65 ± 0.83^{c}	$0.69 \pm 0.65^{b,c}$	<0.001
RU6 – x axis	1.98 ± 0.33^{a}	1.50 ± 0.82^{a}	0.91 ± 0.62^{b}	0.76 ± 0.43^{b}	0.57 ± 0.66^{b}	<0.001
LU6 – x axis	1.93 ± 0.39^{a}	1.62 ± 0.70^{a}	0.96 ± 0.46^{b}	0.80 ± 0.72^{b}	0.73 ± 0.58^{b}	<0.001
U1 midline – y axis	2.07 ± 1.32^{a}	$1.76 \pm 0.92^{a,b}$	1.02 ± 0.74^{c}	$1.21 \pm 0.94^{a,c}$	$1.05 \pm 0.92^{b,c}$	<0.001
RU6 – y axis	$2.11 \pm 1.09^{a,d}$	$1.89 \pm 1.02^{c,d}$	1.33 ± 0.82^{b}	$1.48 \pm 0.78^{b,c}$	1.35 ± 0.72^{b}	0.001
LU6 – y axis	2.04 ± 1.32^{a}	$1.88 \pm 1.07^{a,c}$	1.06 ± 0.85^{b}	$1.40 \pm 0.82^{b,c}$	$1.42 \pm 0.68^{b,c}$	0.001
U1 midline – z axis	1.53 ± 0.89^{a}	$1.08 \pm 0.69^{a,c}$	$0.90 \pm 0.66^{b,c}$	$0.59 \pm 0.48^{b,c}$	$0.58 \pm 0.94^{b,c}$	0.005
RU6 – z axis	1.72 ± 1.07^{a}	$1.22 \pm 0.71^{a,b}$	0.93 ± 0.64^{b}	0.58 ± 0.30^{b}	0.68 ± 0.90^{b}	0.001
LU6 – z axis	1.56 ± 0.96^{a}	$1.20 \pm 0.66^{a,b}$	$1.01 \pm 0.66^{a,b}$	0.69 ± 0.35^{b}	0.66 ± 0.75^{b}	0.007

U1, upper central incisors; RU6, upper right first molar mesiobuccal cusp; LU6, upper left first molar mesiobuccal cusp.
* *P*-value: different letters represent statistically significant differences between values.

The primary outcome variable was the accuracy of orthognathic surgery in all three axes (x, y, and z) for each year. The assessment of time versus accuracy was performed after the subjects included in the study were divided into groups according to the year in which VSP was executed and surgery was performed. The secondary outcome was the overall accuracy, including all landmarks in all axes, for each year of the study. The mean differences between the planned and postoperative results were subdivided into the following categories: <1 mm, 1–2 mm, and >2 mm.

The sample size aimed for a confidence interval of 95% and a confidence level of 0.05. All data collected were analyzed using IBM SPSS Statistics version 22.0 (IBM Corp., Armonk, NY, USA). Intra-observer consistency was evaluated and analyzed by paired t-test. Quantitative variables were expressed as the mean values and standard deviation. Qualitative variables were expressed as the percentage and frequency. All statistical tests were performed considering a significance level of $P < 0.05$. Mean measurements for quantitative variables between qualitative variables were compared by applying one-way analysis of variance (ANOVA), followed by post hoc Games–Howell test when statistical significance was identified.

Results

One hundred and three eligible subject were identified. Two were then excluded due to the lack of an immediate postoperative CBCT scan and one was excluded due to mandible-first surgery. Of the remaining 100 patients, 35 were male and 65 were female; their mean age was 22.1 years (range 14–46 years). The sample size for a population of 103 subjects would require a minimum of 81 cases to meet a confidence interval of 95% and a confidence level of 0.05; therefore, the final sample met the sample size calculation criteria.

The patient sample was distributed into five groups according to the year in which VSP was performed: 2013 ($n = 10$), 2014 ($n = 17$), 2015 ($n = 39$), 2016 ($n = 20$), and 2017 ($n = 14$). The assessment of intra-observer accuracy, as determined by the consistency of the identification of two distinct landmarks (basion and nasion) on two separate occasions, revealed no statistically significant difference for any of the groups, except between the years 2014 and 2015 for one reference landmark in a single direction (basion in the z axis) (Table 1).

The results of the overall linear measurement differences for each landmark in each year are shown in Table 2. For the x axis, the U1 landmark showed decreasing discrepancies from 2013 to 2017, with statistical significance for the year 2013 compared to all other years. Years 2014 and 2016 did not correlate with each other, and years 2015 and 2017 correlated with all years except 2013. Landmarks RU6 and LU6 presented similar results, with decreasing mean values over the years, and with years 2013 and 2014 similar to each other, but distinct from years 2015, 2016, and 2017, which were similar to each other.

For the y axis, the U1 landmark showed decreasing discrepancies from 2013 to 2017, except for a slight increase in mean value from 2015 to 2016; however, this last difference was not statistically significant. Statistical significance was found from year 2013 to years 2015 and 2017, while year 2014 only differed significantly from year 2015. No statistically significant difference was found amongst groups 2015, 2016, and 2017 for this landmark in the y axis. Landmarks RU6 and LU6 presented similar results, showing decreasing discrepancies over the years,

Table 3. Overall accuracy of all differences between planned and postoperative results for all landmarks subdivided into three discrepancy limits; results are presented as the number (%).

	Mean differences between planned and obtained outcomes			*P*-value
	<1 mm	1–2 mm	>2 mm	
Number of measured landmarks	*n* = 462	*n* = 292	*n* = 146	
Year				
2013	17 (18.9%)	33 (36.7%)	40 (44.4%)[b]	<0.001*
2014	47 (30.7%)	66 (43.1%)[b]	40 (26.2%)[b]	
2015	189 (53.8%)	127 (36.2%)	35 (10.0%)	
2016	119 (66.1%)[b]	42 (23.3%)	19 (10.6%)	
2017	90 (71.4%)[b]	24 (19.1%)	12 (9.5%)	

[*] *P*-value: different letters represent statistically significant differences between values.

except for a modest increase in mean values between 2015 and 2016. For landmark RU6, year 2013 statistically correlated only to year 2014, which was also correlated with year 2016. A statistically significant correlation was found among years 2015, 2016, and 2017. For the LU6 landmark, year 2013 only correlated with year 2014, which was also correlated with years 2016 and 2017. No statistically significant difference was found among years 2015, 2016, and 2017 in landmark LU6 as well.

Regarding the *z* axis, all landmarks showed decreasing mean discrepancies from year 2013 to year 2016. For the U1 and RU6 landmarks, discrepancies from year 2013 statistically correlated only to values from year 2014, while there was no statistical significance among years 2014, 2015, 2016, and 2017. Minor changes occurred for the LU6 landmark, with year 2013 showing correlation to years 2014 and 2015, while no statistical significance was found among years 2014, 2015, 2016, and 2017.

The overall accuracy, defined as the secondary outcome, is shown in Table 3 and Fig. 1. Among all axes (*x*, *y*, and *z*), an overall average difference between the planned outcome and the outcome obtained of within 1 mm was observed for 51.3% of the measurements included in the sample, and an increasing accuracy was observed across the years. In 2013, a difference between planned and obtained results of <1 mm was found only for 18.9% of all measurements, and this percentage increased over the years to 71.4% of the measurements in 2017. Mean discrepancies of between 1 mm and 2 mm showed the highest incidence in 2014 (43.1%) and mean discrepancies of >2 mm showed the highest incidence in 2013 (44.4%); the incidence decreased to 19.1% (for discrepancies of 1–2 mm) and 9.5% (for discrepancies of >2 mm) in the year 2017. The incidence of mean discrepancies >2 mm was significantly higher in 2013 and in 2014 than in the other years, while the incidence of discrepancies <1 mm was significantly higher in the more recent years (2016 and 2017).

Discussion

Most of the published literature on VSP has investigated the feasibility of this technique or has emphasized the potential advantages of VSP over conventional methods of orthognathic planning[3,6,12]. However, the impact of differences in algorithms and the rapid development of software technology, as well as the VSP operator ‘learning curve’, have never been addressed in a chronological fashion. The results of this study show a consistent improvement in the accuracy of sagittal and anteroposterior movements from the years 2014 and 2014 to the years 2015, 2016 and 2017, although the accuracy of vertical movements did not show a similar correlation with time.

When evaluating the literature, both early (Hsu et al.[4] and Sun et al.[13]) and more recent studies have shown satisfactory outcomes in terms of accuracy when using VSP for orthognathic surgical planning. In 2013, Sun et al.[13] reported a mean difference between planned and obtained surgical movements of 0.50 ± 0.22 mm in the transverse axis, 0.57 ± 0.35 mm in the vertical direction, and 0.38 ± 0.35 mm in the horizontal direction, although the authors investigated only 15 patients and only one maxillary landmark was analyzed (the edge of the central incisor). Similar outcomes were reported by Hsu et al. in 2013, although the authors showed the anteroposterior movement to be the least accurate outcome variable, with a 1-mm difference between the planned and obtained results[4]. More recent studies have shown a mean difference in maxillary position between the planned and obtained results comparable to the differences reported in these previous studies, as well as to those of the present study. In 2017, Ritto et al.[12] reported a mean linear difference of 0.90 mm for transverse movements, 0.95 mm for anteroposterior movements, and 1.44 mm for vertical movements. The sample of their study included patients treated between 2012 and 2015, although it did not mention the number of patients operated on each year. In part, these previous results are consistent with those of the present study,

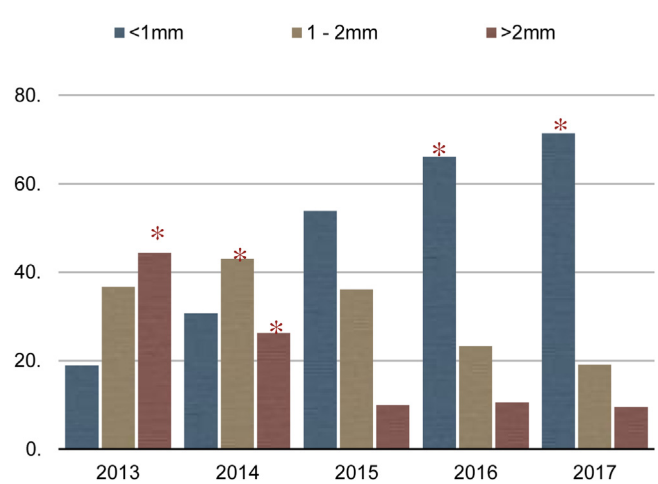

Fig. 1. Percentage of measurements included in each discrepancy limit for each year (the asterisk (*) indicates a statistically significant difference).

which included patients operated on after 2014. Comparing the results of this study to those published in the literature suggests that software updates may not have had an impact on accuracy as much as other factors, including the clinician's learning curve and inherent perioperative sources of error.

Regarding the vertical discrepancies observed in this study, as well as others, several perioperative sources could have played a role. Discrepancies in the condylar position during CBCT and in surgery (whether as a result of the condyles not being located in centric relation during the CBCT, or variations in condylar position during surgery, or both) could affect accuracy, mainly in the vertical and anteroposterior directions. Correct positioning of the condyle within the glenoid fossa in centric relation during preoperative registration, as well as during CBCT scanning and during the surgery, would help to minimize such limitations, although this is challenging. Poor appreciation for condyle positioning on preoperative CBCT scans has been one of the main reasons for surgeons abandoning VSP for orthognathic surgeries[14]. Perez and Ellis proposed that the occlusion should always be verified before surgery, with the patient under general anesthesia, in order to check whether it is in agreement with the preoperative registration[15]. If not, new model surgery must be performed using an intraoperative bite registration and the surgery should be delayed or postponed. Borba et al.[16] assessed occlusal measurements before and after general anesthesia and the influence of sex and type of deformity on such changes. While in most instances centric occlusion could be adequately reproduced under general anesthesia, significant changes in the vertical direction of the mandible were found in class II patients. Another alternative to overcome such inaccuracies would be planning a mandible-first orthognathic surgical sequence[15,16], or to use a waferless system to position the maxilla[17,18].

Maxillary positional inaccuracy could be related to the axis of condylar rotation when vertical movements are planned and executed. The current literature still lacks evidence regarding the precise position in which the condylar hinge axis should be located during three-dimensional landmark placement, as well as the degree and direction of mandibular autorotation. The 'hinge axis concept' maintains that the mandible moves around a transverse horizontal axis through both condyles[19]. Any differences in the position and the direction of autorotation can significantly affect the position of the maxilla, primarily when large vertical movements are planned[20]. As the mouth opens for the placement of maxillomandibular fixation using the intermediate splint, both rotational and translational movements of the condyles may occur, instead of the predicted pure hinge movement, which is the path that VSP and splint fabrication is based upon. Also, even if only pure rotational movement occurs, the hinge axis may very well differ between what was used during VSP and the actual axis in situ during surgery.

Hellsing et al.[19] stated that pure rotation does not occur, and an increase in the occlusal vertical dimension results in positional changes of the condyles in an unpredictable direction. As demonstrated by Travers et al.[21], healthy individuals may perform normal opening with highly variable amounts of condylar rotation and translation, which indicates that the lower incisor opening does not provide reliable information about condylar translation; therefore, its use to predict condylar movement should be limited.

In an attempt to locate the center of mandibular autorotation during maxillary surgical impaction and to identify discrepancies in the resultant mandibular position following maxillary surgical impaction, Wang et al.[22] demonstrated that the center of mandibular autorotation is located, on average, 2.5 mm posterior and 19.6 mm inferior to the radiographic condylar center of the mandible, with tremendous individual variations. There is no consensus regarding the location of the mandibular autorotation center as reported in the literature and these authors do not mention maxillary positioning errors according to the rotation of the mandible. Mandibular rotation in two-dimensional or three-dimensional images may not represent actual clinical scenarios, and determining the center of rotation could affect the accuracy of the surgical prediction in any or multiple directions, thereby resulting in discrepancies in surgical outcomes in the maxilla and/or in the mandible[23].

Another potential source of error could be related to the intraoperative measurement of the maxillary vertical dimension. Even with a rigid external landmark (in this case, a Kirschner wire at nasion), the angulation of the external landmark and the angle at which the measuring device (e.g. caliper) is being used along the coronal plane could affect the accuracy in the vertical direction (parallax error). For example, if a Kirschner wire is placed obliquely to avoid entry into the cranial fossa, a caliper will measure along an oblique line that is different from whichever vertical axis the VSP used. Similarly, if a caliper is rotated along the coronal plane and not parallel to the sagittal plane, the vertical dimension measured on the caliper may not reflect the vertical dimension along the planned vertical axis.

A recent systematic review aiming to propose a universal protocol to assess the accuracy of three-dimensional virtually planned orthognathic surgery, reported a lack of consensus between different centers regarding assessment and validation methods to evaluate maxillary accuracy using VSP[24]. Therefore the authors suggested three ideal criteria currently accepted to validate assessment of the accuracy of virtually planned orthognathic surgery: (1) voxel-based registration, on the cranial base, of planned and postoperative images; (2) automated or semi-automated evaluation of the outcome; and (3) inter- and intra-observer reliability to validate results[24]. One of the strengths of the present study is that the study design followed voxel-based registration of pre- and postoperative CBCT images using the anterior cranial base, although assessment was performed by registration of multiple landmarks and only one observer validated the results. Intra-observer reliability was confirmed by measuring landmarks not affected by orthognathic surgery, and the statistical analysis of these landmarks confirmed its overall reliability.

A limitation of the present study is that it was a single-center study, although the diagnosis, treatment planning, VSP, and surgical techniques used are standard. The results of this study may not be applicable to settings with different case volumes, operator experience with VSP, and surgical techniques. Also, it has been reported that the direction of surgical movement can influence the accuracy of maxillary surgery[25,26]. The present study did not divide patients into different groups according to the direction of movement; instead there was a large variation in maxillary direction and magnitude of movement in all groups, which contributed to the heterogeneity of the sample and reliability of the results. Also, although the learning curve (which can be defined as improving performance over time, or increasing experience or training) is thought to have played a substantial role in the improvement of surgical accuracy, a learning curve cumulative sum analysis (LC-CUSUM) was not performed. LC-CUSUM is a sequential analysis tool originally developed for quality control purposes, which may be used to evaluate when an individual's performance has reached a predefined level of competence. Other possible limitations of the study include the different sample sizes of the groups and inherent biases associated with retrospective studies.

In the authors' collective experience, continuous learning from the routine use of VSP resulted in improved understanding of the three-dimensional relationships of the skeletal structures during the planned surgical movements. Describing his own experience with computer planning in orthognathic surgery, Bell stated that initial obstacles of virtual planning software have been resolved and different software solutions have gained marketability in the meantime[27]. Surgical accuracy and VSP are vertically intrinsically correlated since inaccurate virtual surgical planning cannot lead to an accurate surgical result. However, considering the academic and surgical experience of the main surgeon (MM), only VSP was understood to be an issue. Hence, it would be advisable that VSP be performed by the surgeon who has clinically assessed the patient and will be performing the surgery and not by a third-party who is not involved with the procedure or by a surgeon without experience in both orthognathic surgery and VSP. Solely relying on a VSP technician to provide directions for the planning process devaluates surgeon experience and might result in a blind journey in the surgical field.

Regardless of how surgical planning happens, either from traditional model surgery or contemporary VSP, a hands-on approach based on repetition of a process will likely lead to more precise results as the surgeon overcomes the learning process (learning curve). Hence, an experienced surgeon can definitely take into account intraoperative challenges such as soft tissue resistance while segments are shifted into a new position in major rotational movements (as seen in major occlusal plane alterations or in roll/yaw rotations for asymmetric cases), which cannot be 'felt' during surgical planning.

In conclusion, VSP is an accurate and reproducible method for treatment planning that is reliably transferred to the patient by means of computer-generated surgical splints to accurately reposition the maxilla in the anteroposterior and transverse directions, while the accuracy of maxillary vertical movements relies on subjective preoperative assessment and variations in surgical procedural parameters (internal vs. external landmarks). End-user familiarity and experience, via continuous use of VSP, seem to have contributed to improved accuracy over time; other factors, such as software development and miscellaneous technological updates may have contributed as well, although the VSP planning company used exclusively in this study (3D Systems, Rock Hill, SC, USA) has not varied its methods of VSP significantly since inception. The actual degree to which these factors contributed to the results remains unknown. While continuous software development will certainly occur, it is incumbent upon the surgeon to fully understand the multiple steps of VSP, follow a rational planning protocol and outcomes assessment, and aim to limit planning and perioperative errors and improve accuracy in each minor step along the process. Moreover, the final surgical outcome is a conjunction of virtual planning and actual surgical experience, since one cannot be disassociated from the other. More independent clinical trials are needed to help validate the accuracy and reproducibility of VSP and identify causes of the inaccuracies and recommend methods to prevent these errors.

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Competing interests

Dr Miloro is a consultant for AxoGen, Inc., Alachua, FL, USA. All other authors do not have any relevant financial relationship(s) with a commercial interest.

Ethical approval

University of Illinois at Chicago IRB protocol #2108-0276.

Ethical Approval

The study was previously approved by University of Illinois at Chicago Institutional Review Board (IRB protocol number 2108-0276) and was performed following the Declaration of Helsinki protocol.

Patient consent

Not required. HIPPA Waiver of Authorization granted under 45 CFR164.512.

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